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NATIONAL INVENTORY OF SOURCES AND EMISSIONS: BERYLLIUM, 1968

W. E. Davis and Associates

Prepared for:

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September 1971

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NATIONAL INVENTORY OF SOURCES AND EMISSIONS: BERYLLIUM - 1968

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The inventory of atmospheric emissions has been prepared to provide reliable information regarding the nature, magnitude, and extent of the emissions of beryllium in the United States for the year 1968. Background information concerning the basic characteristics of the beryllium industry has been assembled and included. Brief process descriptions are given. The beryllium emissions and emission factors presented are based chiefly on the summation of information obtained during field trips to inspect the air pollution control equipment used at various locations and observe processing operations. The production and use of beryllium in the United States has been traced and charted for the year 1968. The consumption was 351 short tons, while production from domestic mines was only 7 short tons. About 98% of the beryllium processed was from imported beryl ore, 35% of which was used to produce beryllium metal, about 50% to produce beryllium alloys, about 5% to produce ceramics, and about 10% was lost during processing. Emissions to the atmosphere during 1968 totaled 164 tons.

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by

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9726 Sagamore Road
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Contract No. CPA-70-128

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Office of Air and Water Programs
Office of Air Quality Planning and Standards
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Publication No. APTD-1508

PREFACE

This report was prepared by W. E. Davis & Associates pursuant to Contract No. CPA 70-128 with the Environmental Protection Agency, Office of Air Programs.

The inventory of atmospheric emissions has been prepared to provide reliable information regarding the nature, magnitude, and extent of the emissions of beryllium in the United States for the year 1968.

Background information concerning the basic characteristics of the beryllium industry has been assembled and included. Process descriptions are given, but they are brief, and are limited to the areas that are closely related to existing or potential atmospheric losses of the pollutant.

Due to the limitation of time and funds allotted for the study, the plan was to personally contact the two primary producers and about fifteen percent of the companies in each major emission source group to obtain the required information. It was known that published data concerning emissions of the pollutant were virtually nonexistent, and contacts with industry ascertained that atmospheric emissions were not a matter of record.

The beryllium emissions and emission factors that are presented are based chiefly on the summation of information obtained during field trips to inspect the air pollution control equipment used at various locations and observe processing operations

Beryllium emissions and emission factors are considered to be reasonably accurate

ACKNOWLEDGEMENTS

This was an industry oriented study and the authors express their appreciation to companies and individuals in the beryllium industry for their contributions.

We wish to express our gratitude for the assistance of the Office of Air Programs, and to many branches of the Federal and State Governments.

Our express thanks to Mr. C. V. Spangler, Project Officer, Office of Air Programs, for his helpful guidance.

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SUMMARY

The production and use of beryllium in the United States has been traced and charted for the year 1968. The consumption was 351 short tons, while production from domestic mines was only 7 short tons. About 98 percent of the beryllium processed was from imported beryl ore, part of which was imported during the year and part during prior years. About 35 percent (125 tons) of the beryllium was used to produce beryllium metal, about 50 percent (175 tons) to produce beryllium alloys, about 5 percent (16 tons) to produce ceramics, and the remaining 10 percent (35 tons) was lost during processing.

Emissions to the atmosphere during 1968 totaled 164 tons. Emissions due to the combustion of coal and fuel oil were 147 tons and 8 tons, respectively. Emissions resulting from the production of cast iron were 4 tons.

Emission estimates for coal combustion are considered to be reasonably accurate. They are based on the average beryllium content of many coal samples.

EMISSIONS BY SOURCE
1968

Source Category	Source Group	Emissions - Pounds		Emissions %
Mining			1	--
Processing of Beryllium Metal, Alloys, and Compounds			10,500	3.2
End Product Uses of Beryllium Metal, Alloys, and Compounds:			55	--
	Beryllium Fabrication	13		
	Beryllium Alloys	26		
	Beryllia Ceramics	16		
Other Sources of Beryllium Emissions:			318,000	96.8
	Coal	294,000		
	Oil	16,000		
	Miscellaneous	8,000		
TOTAL			328,556 or 164 tons	100.0

EMISSIONS BY STATES
1968

State	Beryllium Emissions Short Tons
Pennsylvania and Ohio	41
Illinois	12
Indiana	12
Michigan	11
New York	7
Alabama and Mississippi	7
West Virginia	7
Kentucky	5
North Carolina	5
Tennessee	5
Wisconsin	4
Delaware and Maryland	4
Virginia	4
Georgia and Florida	4
All Other States	24
Undistributed	12
TOTAL	164

EMISSION FACTORS

The emission factors given herein are believed to be the best currently available. They were determined through a combination of methods consisting of: (1) direct observation of emission data and other related plant processing and engineering data where available; (2) estimations based on information obtained from literature, plant operators, and others knowledgeable in the field; (3) calculations based on experience and personal knowledge of metallurgical processing operations; and (4) specific analytical results (in the case of coal and fuel oil).

The basic data used to calculate the emission factors are contained in the files of the Contractor and the Office of Air Programs of the Environmental Protection Agency. Readers of this document are encouraged to submit data to the EPA in confirmation of these factors or additional data which can be used to further refine the factors in subsequent publications.

TABLE I

EMISSION FACTORS

Mining	0.2 lb/ton of beryllium produced
Processing of Beryllium Metal, Alloys, and Compounds	30 lb/ton of beryllium processed
End Product Uses of Beryllium Metal, Alloys, and Compounds	
Beryllium fabrication	10 lb/100 tons of beryllium processed
Beryllium alloys	15 lb/100 tons of beryllium processed
Beryllia ceramics	1 lb/ton of beryllium processed
Other Sources of Beryllium Emissions	
Coal	0.58 lb/1,000 tons of coal burned
Oil	0.03 lb/1,000 bbls of oil burned

MINERAL SOURCES OF BERYLLIUM

Beryllium (Be), a grayish metal, is the only light-weight metal with a high melting point. Its specific gravity (1.85) is only slightly greater than magnesium, but its melting point (1,283 C) is nearly twice as high. It also has a very high strength-to-weight ratio, great stiffness, and valuable nuclear properties.

The earth's crust is estimated to contain 10 ppm beryllium [1] compared with 0.1 ppm silver and 16 ppm lead. Beryllium is widely distributed geographically but is found in concentrated form in relatively few minerals. Beryl, bertrandite, phenacite, chrysoberyl, and barylite are some of the best known of the thirty or more beryllium minerals, but the principal commercial source prior to 1968 has been beryl.

Usually beryl is found associated with other minerals in heterogeneous granite pegmatites where the beryl occurs in enriched zones; however, pegmatites are seldom mined for beryl alone. More often the mineral is recovered as a co-product or by-product while recovering feldspar, mica,

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1- Clark, F. W. and Washington, H. S. U. S. Geological Survey Professional Papers 127. 1924.

cassiterite, columbite, quartz, tantalite, kaolinite, hematite, and lithium minerals. Many deposits contain less than one hundred tons of cobbed beryl.

Beryllium also occurs in nonpegmatite deposits. Bertrandite has been found associated with fluorite, montmorillonite, opal, and chalcedony at Spor Mountain, Utah; commercial mining in this district began during 1969. Similar deposits have been found elsewhere in Utah. In Nevada, phenacite and bertrandite occur with scheelite, flourite, pyrite, and other minerals in limestone. In Colorado, beryl and bertrandite occur with fluorite in mica-quartz crystalline rock. In Labrador, barylite occurs in small veins with quartz and albite; in Mexico, bertrandite is found in fluorite which also contains other minerals.

Beryl, when pure, is a beryllium aluminum silicate, containing about 14 percent BeO, 19 percent Al_2O_3, and 67 percent SiO_2. The precious forms of beryl, emerald, and aquamarine approach the pure form in composition; however, the commercial grades generally contain 11 to 13 percent BeO, 17 to 19 percent Al_2O_3, 67 to 70 percent SiO_2, and 2 to 4 percent metal oxides.

During recent years the major world sources of ores that contain beryllium have been India, Brazil, Uganda, Mozambique, Argentina, and the U.S.S.R. Even though the United States has not been a major producer in the past, small quantities of beryl ore have been mined in Colorado, South Dakota, New Mexico, and West Virginia.

Other domestic sources of beryllium have been investigated and reported by the Bureau of Mines, the U. S. Geological Survey, and others. These reports indicate some beryllium is found in coal and oil, as well as in pegmatite ores mined extensively in North Carolina, principally for the production of feldspar, quartz, mica, and spodumene.

MATERIAL FLOW THROUGH THE ECONOMY

The sources and uses of beryllium in the United States during 1968 are shown in Figure I. About 44 percent of the beryl ore that was processed was imported, 34 percent was from Government stocks, 20 percent was from industry stocks, and only 2 percent was from domestic mines.

Beryl Ore Imports - In 1968 the imports of beryl ore totaled 3,822 short tons (Be content - 153 short tons). About 42 percent was imported from Brazil, 14 percent from Argentina, 10 percent from Uganda, 9 percent from the Republic of South Africa, and 5 percent or less from each of ten other countries [1].

Beryl Ore Stocks - At the beginning of the year industry stocks of beryl ore were 8,177 short tons [2], but by the end of the year the total was only 6,390 short tons [1], a decrease of 1,787 short tons (71 short tons Be content). During the same period Government stocks of beryl also decreased 3,000 short tons (120 short tons Be content) [3].

1- Minerals Yearbook: Bureau of Mines; 1968.

2- Minerals Yearbook: Bureau of Mines; 1967.

3- Private communication with industrial sources.

Beryllium Uses - A large proportion of the beryllium is ultimately used in space and national defense applications. Information regarding many of these uses is classified and the details are not revealed in this report. Other uses of beryllium are discussed in detail in the following section.

BERYLLIUM

MATERIAL FLOW THROUGH THE ECONOMY - 1968

(Short Tons - Be Content)

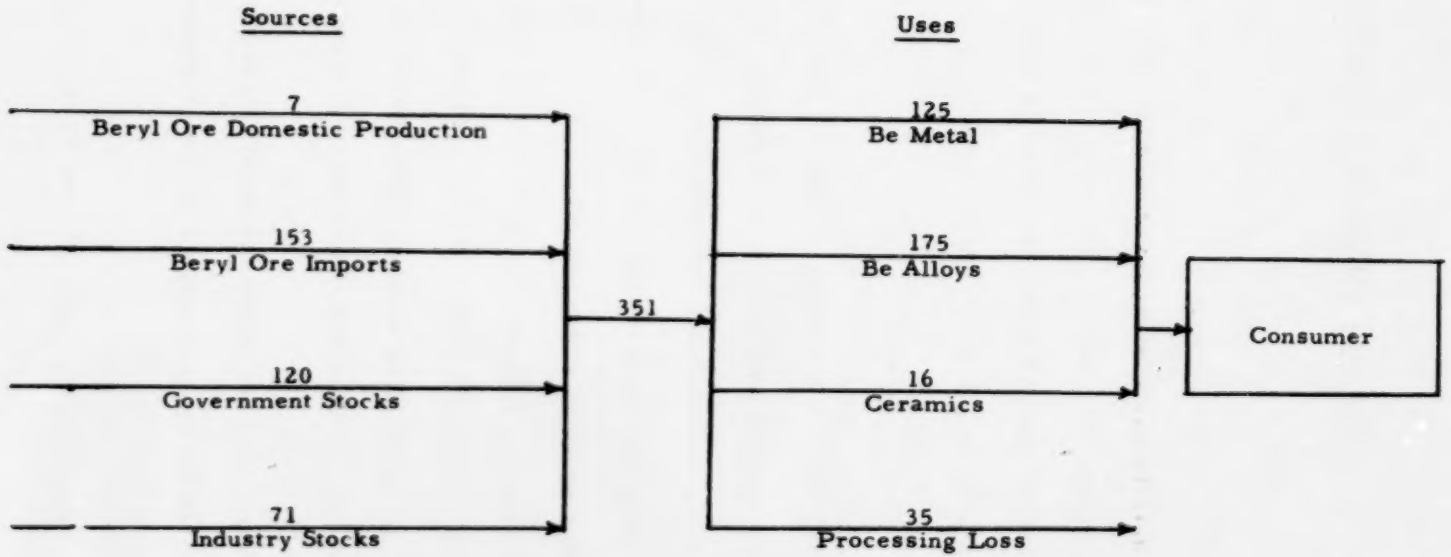

Figure I

USES AND EMISSIONS OF BERYLLIUM

MINING

In the United States hand-sorted beryl ore was produced in Colorado, New Mexico, and South Dakota during 1968, but domestic production for the year was only 160 short tons [1]/ containing about 4 percent beryllium (Be content - 7 short tons).

Prior to 1969 beryllium ore mined in the United States was from open pits or shallow underground workings and most of the ore was concentrated by hand-sorting. The mining was usually done on a small scale by crude opencut methods. It commenced on an outcrop where the minerals of value could be seen and cuts were made or pits were sunk by drilling and blasting the rock. The cycle of drilling, blasting, cobbing, and hauling waste to dumps was repeated until the operation could no longer be worked economically.

Output from the mines remained at a low level in the United States for several years even though domestic consumption

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1 Minerals Yearbook. Bureau of Mines. 1968.

increased substantially. However, construction of new large-scale facilities was commenced during 1968 by Brush Beryllium Company at Spor Mountain in Utah. At the open-pit mine site removal of overburden was started about the middle of the year. Forty-seven miles from the mine, at a location near Delta, Utah, construction of the mill was in progress and completion was scheduled for midyear 1969. Even though there were no emissions from operations in Utah during 1968, this will be a significant factor to be taken into account in future years.

Emissions from Mining - While this study was in progress, several mining companies were contacted concerning their operations and their emissions to the atmosphere. They stated that records of beryllium emissions were not maintained.

Beryllium emissions to the atmosphere from sources of mining are estimated at 0.2 pound per ton of beryllium handled. This gives a figure of 1.4 pounds of beryllium emitted to the atmosphere during 1968. This estimate is made by The Contractor on the basis of better known emissions from similar mining operations that have been studied in more depth for other trace metal emission reports.

Beryllium is also found associated with minerals other than beryl and bertrandite. In copper mining and smelting it is often present in the ore in trace amounts, but there is no by-product beryllium recovery. Another similar example is mining of spodumene at Kings Mountain in North Carolina. Mining at that location is principally for the recovery of lithium even though the ore uniformly contains about 0.05 percent BeO according to United States and North Carolina geological surveys.

PROCESSING OF BERYLLIUM METAL, ALLOYS AND COMPOUNDS

The production of beryllium products in 1968 was principally from imported ores processed by the Brush Beryllium Company, Elmore, Ohio, and Kawecki Berylco Industries, Inc., Hazelton, Pennsylvania. Although these companies use different processing methods, the basic product made from beryl ore is beryllium hydroxide. This material is further processed to produce beryllium metal, beryllium oxide, and master alloys. During 1968 the beryllium processed into products was 351 short tons (Be content) [1].

Beryllium Hydroxide - In the Copaux-Kawecki fluoride process used by Kawecki Berylco Industries, the beryl ore is finely powdered by dry grinding to minus 200 mesh, then mixed with soda ash and sodium fluosilicate prior to sintering at 1,400 F. After sintering, the product is crushed, ground, leached with water, and the insolubles are filtered off to waste. The filtrate is treated with caustic soda to precipitate beryllium hydroxide.

The Sawyer-Kjellgren sulfate extraction process, as used

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1. Private communication with industrial sources.

by the Brush Beryllium Company, is a process in which the beryl ore is first crushed and melted at about 3,200 F. The beryl is then quenched in cold water and the crystalline structure is destroyed. Next, the beryl glass is heated to about 1,700 F in a gas-fired rotary kiln, then ground in a ball mill to increase its activity prior to the addition of sulfuric acid. Sulfation is followed by water leaching and the resulting silica sludge is discarded. The soluble beryllium and aluminum sulfates are extracted with the water and the bulk of the aluminum present is separated as ammonium alum by adding ammonium hydroxide. The solution is cooled to cause crystallization and the alum is removed by centrifuging. Next, chelating agents are added to the filtrate and a sodium hydroxide solution is introduced to produce sodium beryllate. Hydrolysis follows and the precipitate, beryllium hydroxide, is separated by centrifuging.

Beryllium Oxide - In one method of producing beryllium oxide, the beryllium hydroxide is first redissolved in water, sulfuric acid, and ammonium sulfide. Then the solution is passed through the steps of filtration, evaporation, and crystallization. centrifuging follows to obtain beryllium sulfate. The final steps are blending and calcination at about 1,900 F.

Beryllium-Copper Alloys - The first step in the production of beryllium-copper alloys is to prepare a master alloy. Beryllium hydroxide is calcined at about 800 F to form beryllium oxide. Then weighed quantities of carbon powder, copper, and beryllium oxide are mixed and melted in an electric arc furnace. The product, beryllium-copper master alloy, is cast into ingots containing about 4 percent beryllium.

In the final step, the master alloy and copper are melted together in an induction furnace to form beryllium-copper alloy containing about 2 percent beryllium.

Beryllium Metal - Both of the primary producers of beryllium in the United States rely on the same basic principals for the production of beryllium fluoride, but there are certain differences in the process details. The Brush Beryllium Company uses the Schwenzfeier-Pomelee purification process [1/] and is able to use a rather impure input material. The hydroxide product of the sulfate extraction process and various scrap recycle products are used as the input to the beryllium fluoride process. These feed materials are

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1/ White, D. W. and Burke, J. E.: The Metal Beryllium; American Society for Metals; Cleveland, Ohio; 1959.

dissolved in ammonium bifluoride in a step which includes the addition of calcium carbonate. The resulting solution enters a thickener under conditions where precipitation of all heavy-metal impurities occurs, except manganese and chromium. Lead dioxide is then added to the solution to convert the manganese content to insoluble manganese dioxide and the chromium content to insoluble lead chromate. A filtration step follows, then a sulfide treatment and a second filtration step. At this point the solution enters a vacuum crystallizer, then passes through a centrifuge and a dryer on its way to a decomposition furnace. In the furnace, ammonium fluoride is driven off into a scrubber while beryllium fluoride flows from the bottom and is solidified.

In the next step, magnesium and the beryllium fluoride are charged to a reduction furnace in solid form. An excess of beryllium fluoride is used in relation to the amount of magnesium [1] in order to produce a slag of magnesium fluoride and beryllium fluoride with a melting point substantially below the melting point of beryllium. The beryllium fluoride excess is essential to permit separation of the beryllium

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1- U. S. Patent No. 2,384,291, Aug. 7, 1945 B. R. F. Kjellgren to the Brush Beryllium Company.

metal reaction product from the slag by water leaching.

Solid beryllium is recovered after the reaction is completed by raising the temperature above the melting point of beryllium to approximately 2,300 F. At this temperature the slag is very liquid and the molten beryllium floats on top. The mass is then poured into a receiving pot where it solidifies. Next, this product is crushed and then water-leached in a ball mill. During leaching the excess beryllium fluoride is quickly dissolved; the metallic beryllium is released in the form of pebbles that generally contain about 3 percent trapped slag and unreacted magnesium. To remove these impurities, the pebbles are vacuum-melted and cast into ingots. During this operation magnesium is eliminated from the melt in the vapor form. Excess beryllium fluoride is also vaporized. Nonvolatiles separate from the melt as a dross and are removed from the crucible after the purified metal has been poured into the ingot mold.

Emissions from the Processing of Beryllium Metal, Alloys, and Compounds - During the past 25 years it has been recognized that excessive beryllium concentrations in the atmosphere are a serious hazard to health. As a result many controls have been installed at industrial plants where beryllium

is processed.

During this study meetings were held with Brush Beryllium Company at Elmore, Ohio, and Kawecki Berylco Industries at Reading, Pennsylvania. Both companies furnished detailed information regarding the use of air pollution control equipment as shown in Tables II and III. They also provided information concerning beryllium concentrations in the atmosphere surrounding plant sites, but could not provide stack emission data.

During the months of May, June, and July, 1971, by agreement with the Brush Beryllium Company and Kawecki Berylco Industries, field crews of the Environmental Protection Agency conducted preliminary field source sampling tests at the metallurgical processing facilities of the two beryllium companies. These tests covered major stacks but did not cover all sources of atmospheric emissions. Based on the known results of these preliminary tests the EPA estimates that total emissions during 1968 from all metallurgical processing facilities of both companies were no less than 30 pounds per day, average for the year, or 10,500 pounds for a year of 350 operating days [1].

1- Private communication from the Environmental Protection Agency, Office of Air Programs: July 14, 1971.

Further refinement to determine actual emissions from these plants awaits the results of a more complete testing program, now planned as of the date of release of this report.

TABLE II

AIR POLLUTION CONTROL EQUIPMENT
BRUSH BERYLLIUM COMPANY - ELMORE, OHIO

Production Area	Process Description	Control Equipment
Beryllium Hydroxide	Ore storage, crushing and melting	Wet cyclone and baghouse
	Quenching, heat treating and grinding	Cyclone and baghouse
	Sulfation and dissolving	Packed tower - water scrubbing
	Leaching, crystallization and beryllation	Ventilation
Beryllium Pebbles	Mixing, thickening, filtering and sulfide treating	Packed tower - water scrubbing
	Crystallizing and centrifuging	Baghouse
	Decomposition furnace	Packed tower - two scrubbers in series
	Reduction furnace	Venturi scrubber and packed tower
	Crushing	Packed tower
Beryllium Metal	Pebble melting and casting	Packed tower
	Billet cleaning and inspection	Baghouse
	Chipping, sizing, screening and blending	Cyclone and baghouse
	Die loading, hot pressing, rough and finish machining	Cyclone and baghouse

Beryllium Oxide	Dissolving, filtering, evaporation and crystallization	Ventilation
	Blending and calcining	Packed tower-caustic scrubbing
Master Alloy	Calcining	Baghouse
	Mixing	Baghouse
	Arc furnace	Cyclone and baghouse
Beryllium Copper	Melting	Baghouse
	Casting	Baghouse

TABLE III

AIR POLLUTION CONTROL EQUIPMENT
KAWECKI BERYLCO INDUSTRIES, INC.
HAZELTON, PENNSYLVANIA

Production Area	Process Description	Control Equipment
Beryllium Hydroxide	Ore handling and grinding	Cyclone and baghouse
	Sintering	Venturi scrubber
	Crushing and grinding	Cyclone and baghouse
	Leaching and filtering	Hydraulic scrubber and venturi scrubber
Beryllium Beads	Mixing, purifying and filtering	Hydraulic scrubber and demister
	Evaporation	Hydraulic scrubber
	Drying	Venturi scrubber and demister
	Decomposition furnace	Venturi scrubber and demister
	Reduction furnace	Venturi scrubber, cyclone and baghouse
	Crushing and milling	Scrubber and demister
Beryllium Metal	Melting and casting	Cyclone and baghouse
	Billet cleaning	Scrubber and demister
	Chipping	Cyclone and baghouse
	Grinding	Cyclone and baghouse

Beryllium Metal (cont.)	Sizing, screening, blending and loading	Baghouse
	Vacuum hot pressing	Baghouse
	Machining	Cyclone and baghouse

Beryllium Oxide	Dissolving, filtering, evaporation and crystallization	Ventilation
	Blending and calcining	Packed tower-caustic scrubbing
Master Alloy	Calcining	Baghouse
	Mixing	Baghouse
	Arc furnace	Cyclone and baghouse
Beryllium Copper	Melting	Baghouse
	Casting	Baghouse

END PRODUCT USES OF BERYLLIUM METAL, ALLOYS, AND COMPOUNDS

The use of beryllium has grown from 180 short tons in 1964 to 351 short tons in 1968. Much of this rapid growth has been due to the increased use of beryllium metal in high-speed aircraft, missles, and space exploration.

Beryllium Metal - Beryllium metal has the unusual physical properties of high stiffness, high heat capacity, and low density. It is used in nuclear reactors as a moderator and reflector material, as well as in gyroscopes, accelerometers, internal guidance systems parts for high-speed flight and marine navigation, rocket propellant fuel, airplane brakes, and heat shields for space capsules. Newly reported uses include rotor blades and other parts for gas turbine engines, solar cell mounting boards for satellites, mirrors, and other optical parts. During 1968 the beryllium metal produced was 125 short tons 1/.

Beryllium-Copper Alloy - Beryllium copper has high electrical and thermal conductivity coupled with strength and resistance to fatigue at elevated temperatures. There are

1 - Private communication with Brush Beryllium Company.

many uses for beryllium-copper including springs, bellows, diaphragms, electrical contacts, aircraft engine parts, plastic molds, marine propellers, gears, bearings and bearing retainer rings, precision castings, and rollers. New applications include housings to protect undersea telephone systems, automobile starter springs, bucket wheels used in instruments which measure the velocity of water, and antennas for space vehicles and satellites.

In the United States during 1968 the beryllium used in beryllium-copper alloys totaled 175 short tons [1].

Ceramics - Beryllium in the form of beryllium oxide has ceramic applications. It is useful for certain ceramics because of a high melting point, high thermal conductivity, high specific heat, and a high electrical insulation resistance over a wide temperature range. Beryllia ceramics are used in high-voltage electrical porcelains, suspension insulators, spark plugs, and microwave windows.

There were 16 tons of contained beryllium used in beryllia ceramics during 1968 [1].

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1 - Private communication with Brush Beryllium Company.

End Product Emissions of Beryllium Metal, Alloys, and Compounds - The companies manufacturing end products of beryllium that were contacted during this study, without exception, advised that they do not maintain records of stack samples. Most of them sample in-plant air at regular intervals, but very few sample out-plant air.

Special ventilation systems are incorporated in these facilities; however, the type of system and the air pollution control equipment that is used varies considerably. In general, the small fabricators are not as strict with their environmental monitoring as the metallurgical processing companies or the larger reprocessors. Table IV shows the type of ventilation and equipment used by typical beryllium metal fabricators.

Beryllium Fabrication - Beryllium metal is generally purchased as rod, bar, or billet for use in making aircraft, computer, and spacecraft parts. The usual fabrication operations include turning, milling, drilling, reaming, grinding, honing, sawing, and abrasive cutting. Chemical and electrochemical procedures are also employed. Losses may occur in dust form during these operations.

TABLE IV

INDUSTRIAL DATA - AIR POLLUTION CONTROL

Code No.	Ventilation System	Control Equipment	Waste Type	Waste Packaging	Waste Disposal
3.101	Flexible ducts	Cyclone Baghouse Absolute filter	Solid	Plastic bags	Local contract
3.102	Local	None	Solid Liquid	Plastic bags	Local Sewer
3.103	Local Flexible ducts	Absolute filter	Solid Liquid	Plastic bags	Commercial Sewer Burial
3.104	Central Flexible ducts Local	Cyclone Baghouse Absolute filter	Solid Liquid	Plastic bags Metal drums	Local Sludge separator Sewer
3.105	Local Flexible ducts	Chemical Scrubber Cyclone filter	Solid Liquid	Plastic bags Metal drums	City dump
3.106	Central Flexible ducts	Absolute filters	Solid Liquid	Plastic drums	Return to supplier
3.107	Central Flexible ducts	Absolute filter	Solid Liquid	Plastic drums	Local or Return to supplier
3.108	Central Flexible ducts	Baghouse	Solid Liquid	Plastic drums	Return to supplier

At one large plant all beryllium machining except deburring is accomplished by wet process methods. The deburring operation is enclosed in a hood that is maintained under negative pressure, and the exhaust air is passed through absolute filters before it is returned to the room.

At another location where machining is done under dry conditions, the drilling, sawing, and cutting operations are served by close-capture, high-velocity exhaust hoses held within one base diameter of the point of operation. Ventilated enclosures are used for wet and dry sanding, vapor honing, and wet abrasive cutoff wheels. Lateral slot exhaust is used for acid etching, chem-milling, electrical discharge machines, and counter sinking.

At three small plants where operations were studied, beryllium machining was not separated from other parts of the shop area. At one facility in plant air samples are collected frequently, but the other two have no regular sampling schedule.

An emission factor of 10 pounds beryllium per 100 tons of beryllium metal processed is based on estimates obtained from fabricators. In 1968 the beryllium emissions to the

atmosphere due to fabricating beryllium metal were 13 pounds.

Field source sampling by the EPA is planned for certain facilities, which will refine the emission factors given above.

Beryllium Alloys - Beryllium-copper is the principal alloy and most plants using this material do not remelt or make basic changes in the alloy. The processing generally involves stamping or drawing into finished shapes.

An emission factor of 15 pounds beryllium per 100 tons of beryllium processed is estimated as the average for beryllium alloys. The total emissions to the atmosphere during 1968 were 26 pounds.

Beryllia Ceramics - Beryllia is one of the best refractory materials known and it can be fabricated by normal ceramic processes. The principal emission hazard arises in the original fabrication of the ceramics, where beryllium oxide dust or fume may be inhaled. Machining of parts also gives rise to dust, but in storage or final handling of finished articles there is little danger of emissions except from dusting due to attrition or breakage.

One ceramic operation is briefly described as a process commencing with beryl and other materials batched into a large floor cistern containing water. After milling, wet screening, and adjustments, the glaze is applied to the unfired porcelain. When fired, the glaze is permanently fused to the ceramic article. A typical glaze contains about 2 percent beryl.

The ventilation systems inspected during this study included glove boxes, hoods, central ventilation ducts, and absolute filters. Some reprocessing companies contacted claimed no loss of beryllium to the atmosphere, while others indicated their loss did not exceed 2 percent.

An emission factor of one pound per ton of beryllium processed is estimated as the average emission rate for beryllia ceramics. The total emissions to the atmosphere during 1968 were 16 pounds. This emission estimate was made by The Contractor on the basis of information supplied by the manufacturers.

Rocket Propellants - Beryllium has been used in solid rocket fuels, but due to its high toxicity its use for that purpose has been virtually discontinued. Even though most of

the test work was done prior to 1968, a brief description of fuel manufacturing is included.

The beryllium is usually received in powder form in polyethylene containers packed in steel drums. It is added to other materials in a dough mixer, vacuum cast, cured, and machined into final shapes. Emissions occur during handling the dry powder and during the machining.

During 1967 strict standards were set by the Public Health Service followed by a Department of Defense order limiting testing by Government agencies and their subcontractors. With these restrictions, it is doubtful there will be any future emissions.

Spacecraft Reactors - Analytical studies have been conducted to determine re-entry ablation of beryllium in SNAP-10A reactor reflectors, and the toxic hazard produced at ground level by the resultant residue. It has been concluded that varying degrees of ablation will occur, but that no ground level toxic hazard will exist even with a reflector completely ablated at the lowest possible ablation altitude [1].

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1 - Field, A. L. Jr., "Analytical Studies of Beryllium Ablation and Dispersion During Re-Entry"; J. Spacecraft; 1; No. 1, Jan. 1964.

OTHER SOURCES OF BERYLLIUM EMISSIONS

COAL

A study has been made regarding emissions from coal fired power plants and the emissions of beryllium have been recorded. Six power boilers were tested, each a different type, and each value reported was the average of at least two tests. Two of the boilers were fired with Illinois coal; two burned Pennsylvania coal; one used some coal from Ohio and some from West Virginia; one burned part Kentucky and part West Virginia coal. Beryllium concentrations in the fly ash samples taken before fly ash collection ranged from 0.20 to 0.94 grains per scf x 10^{-4}. The average was 0.45 grains per scf x 10^{-4}. In the samples taken after fly ash collection, the beryllium concentration ranged from 0.02 to 0.24 grains per scf x 10^{-4} and the average was 0.11 grains per scf x 10^{-4} [1]. Calculations have been made based on 508,990,000 tons of coal consumed in the United States during 1968 [2], 90 percent application

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1- Cuffe, Stanley T. and Gerstle, Richard W.; "Emissions from Coal Fired Power Plants". Public Health Service Publication No. 999-AP-35; 1967.

2- Minerals Yearbook; Bureau of Mines; 1968.

of control, 160 scf of flue gas per pound of coal, and the average beryllium concentrations in fly ash stated above. According to this method the beryllium emissions for 1968 due to the combustion of coal were 167 tons.

$$\frac{508,990,000 \times 160 \times 2,000}{7,000 \times 2,000}\left[(0.11 \times 10^{-4} \times 0.9) + (0.45 \times 10^{-4} \times 0.1)\right] = 167$$

Many samples of coal have been analyzed and the beryllium content has been reported as shown in Table V. Calculations have also been made based on a concentration of 1.9 ppm beryllium in coal, 90 percent application of control, 85 percent efficiency of control, and fly ash at 65 percent of total ash. The beryllium emissions calculated by this method total 147 tons.

$$508,990,000 \times 1.9 \times 10^{-6} \times 0.65\left[1 - (0.85 \times 0.90)\right] = 147$$

In this report the figure of 147 tons is used as the beryllium emissions to the atmosphere during 1968 due to the combustion of coal.

TABLE V

AVERAGE MINOR ELEMENT CONTENTS OF COAL FROM VARIOUS REGIONS OF THE UNITED STATES [1]

Region	Ash Content of Coal - %	Be Content of Coal - ppm
Northern Great Plains	13.42	1.5
Eastern Interior	6.16	2.5
Appalachian	6.11	2.5
Western and Southwestern	NR*	1.1
Average Beryllium Content in Coal		1.9

*Not Reported

NOTE - It is anticipated that, with reference to the largest source of emissions for 1968, from coal (294,000 pounds), the ONRL in a joint program with TVA will conduct a coal fired boiler plant test aimed at a complete materials balance for all trace metals. For oil fired boiler plants, the second largest suspected source, EPA has obtained residual fuel samples which await analysis as of the date of the release of this report.

1- The above table based on U. S. Geological Survey Bulletins 1117-C and 1117-D.

OIL

Data regarding the beryllium content of crude and residual oils used in the United States is virtually nonexistent. Only one large electric utility company was able to furnish data showing the beryllium content of residual oil. That company reported the beryllium content of the oil used during 1968 as less than 0.1 ppm.

The residual oil used in the United States during 1968, exclusive of use in vessels, was 581.9 million barrels. The oil, containing beryllium at an estimated 0.08 ppm, was used by industrials, electric utility companies, railroads, oil companies, and the military, as well as for heating (Table VI).

RESIDUAL OIL DATA - 1968

Residual Oil Burned (bbls)	581,900,000
Pounds per Barrel	340
Beryllium Content of Oil (ppm)	0.08

During 1968 beryllium emissions to the atmosphere due to the combustion of residual oil totaled 8 tons.

TABLE VI

SHIPMENTS OF RESIDUAL FUEL OIL IN THE UNITED STATES - 1968

Use	Million Barrels
Heating	174.3
Industrial	175.0
Electric Utilities	185.0
Military and Other	47.6
	581.9
State	
New York	116.4
Massachusetts	67.8
New Jersey	62.6
California	51.8
Pennsylvania	42.4
Florida	38.6
Connecticut	28.1
Illinois	24.1
Virginia	12.0
Indiana	11.4
Washington	10.0
Other States	
Pacific-Mountain	25.5
North Central	23.6
Southern	48.3
Northeast	19.3
	581.9

"Shipments of Fuel Oil & Kerosine in 1968"; Mineral Industry Surveys; U. S. Dept. of the Interior; U. S. Bureau of Mines; Sept. 17, 1969.

INCINERATION

Those references that list the major emission sources of beryllium include the production of beryllium hydroxide, beryllium metal, and beryllium oxide, as well as the combustion as coal. Few sources mention emissions that may occur in connection with scrap and waste disposal.

The possibility of significant emissions from municipal incinerators or sewage disposal plants is considered remote. The ores are not widely distributed and only a small quantity of metal, alloys, and compounds are incorporated into consumer products.

Solid Waste Material from Beryllium Fabrication - Information was obtained during this study regarding the handling of waste and scrap materials that result from the machining of beryllium metal. All fabricators contacted reported that scrap is collected, packaged, and labeled for return to the supplier or sale through a dealer. The usual practice is to package the material in polyethylene bags inside steel drums.

Waste material in solid form that is contaminated with beryllium and is not suitable for sale is usually collected, packaged,

and labeled in the control area before it is turned over to an approved contractor for disposal. In a few instances the fabricator returns the waste to the producer for disposal.

Contaminated liquid waste, such as the coolant from machining operations, is sometimes discarded to the sanitary sewer; in some instances it is disposed of through an approved contractor.

During 1968 the beryllium emissions to the atmosphere due to the disposal of waste from machining operations were negligible.

MISCELLANEOUS EMISSIONS

During this study spectrographic analyses of dust samples from foundries have been examined and they show the dust contains beryllium, arsenic, manganese, vanadium, cadmium, nickel, barium, copper, zinc, and 19 other elements. This information confirms that foundries and possibly steel mills are sources of beryllium emissions to the atmosphere.

In spite of recent advancements in the technology of melting with electric arc and induction furnaces, the cupola is still the most popular method for producing cast iron. The rate of particulate emissions from gray iron cupolas has been reported as 4 to 26 pounds per ton of process weight not including emissions from handling, storage, charging, or other non-melting operations.

Based on this information obtained from industry, the particulate emission factor is estimated at 22 pounds per ton of process weight including melting and non melting operations. The beryllium content of the particulate is 0.003 percent [1]/ and the degree of emission control approximately 25 percent.

1- Private communication with industrial source.

During 1968 the pig iron and scrap used by iron foundries totaled 16,788,000 short tons [1]. Beryllium emissions to the atmosphere due to the production of cast iron were estimated by the Contractor to be 4 tons.

1- Minerals Yearbook; Bureau of Mines; 1968.

APPENDIX A

COMPANIES DEALING IN BERYLLIUM AND BERYLLIUM ALLOYS

CALIFORNIA	LOCATION
Electronic Space Products, Inc.	Los Angeles
Lockheed Missiles and Space Co.	Sunnyvale
North American Rockwell Corp.	El Segundo
Solar Aircraft Company	San Diego
Whittaker Corporation	Los Angeles
COLORADO	
Beryl Ores Company	Arvada
Coors Porcelain Company	Golden
Dow Chemical Company	Rocky Flats
U. S. Beryllium Corporation	Pueblo
FLORIDA	
American Beryllium Company, Inc.	Sarasota
ILLINOIS	
D & S Wire, Incorporated	Chicago
Goldsmith Chemical and Metal Corp.	Evanston
Tri-Cast Corporation	Chicago
IOWA	
Alloy Metal Products, Incorporated	Davenport
MARYLAND	
Max Zuckerman & Sons	Owings Mills
MASSACHUSETTS	
Leach and Garner Company	Attleboro
Whittaker Corporation	West Concord

MICHIGAN

Champion Spark Plug Company	Detroit
Speedring Corporation	Warren

MISSOURI

McDonnell-Douglas Corporation	St. Louis

NEW JERSEY

Allied Chemical Corporation	Morristown
J. T. Baker Chemical Company	Phillipsburg
Be Cu Manufacturing Company, Inc.	Scotch Plains
Braun H. Tool and Instrument Co., Inc.	Hawthorne
Consolidated Ceramics and Metalizing Corporation	Flemington
Englehard Industries, Incorporated	Newark
Little Falls Alloys, Incorporated	Paterson
Machined-Shapes, Incorporated	East Rutherford
Mini-Tool Technical Industries, Inc.	Ridgefield
National Beryllia Corporation	Haskell
Var-Lac-Oid Chemical Company	Elizabeth

NEW YORK

Alloys Unlimited, Incorporated	Melville
American Precision Industries, Inc.	East Aurora
American Silver Company, Inc.	Flushing
Astrometal Company	Yonkers
Atomergic Chemetals Company	Carle Place
Barden-Leemath	Woodbury, L.I.
Belmont Smelting & Refining Works	Brooklyn
Beryllium Manufacturing Corp.	Valley Stream, L.I.
Beryllium Metals & Chemicals Corp.	New York
City Chemical Corporation	New York
T. E. Conklin Brass & Copper Co.	New York
General Aerospace Materials Corp.	Plainview, L.I.
General Astrometals Corp.	Yonkers
International Selling Corporation	New York
Keystone Corporation	Buffalo

Lapp Insulator Company	Le Roy
Loral Corporation	Scarsdale
MKB Manufacturing Corporation	Deer Park, L.I.
A. D. Mackay, Inc.	New York
Metallurg, Inc.	New York
Pancoast International Corporation	New York
Philipp Brothers	New York
Saturn Industries, Inc.	New York
Semi Alloys, Inc.	Mount Vernon
C. Tennant Sons & Company	New York
United Mineral and Chemical Corp.	New York

OHIO

Brush Beryllium Company	Cleveland
Clifton Products, Incorporated	Plainesville
Ferriot Brothers, Incorporated	Akron

PENNSYLVANIA

Aluminum Company of America	Pittsburgh
Beryllium Corporation	Reading
Bram Metallurgical Chemical Co.	Philadelphia
Foote Mineral Company	Exton
Kawecki-Berylco Industries, Inc.	Reading
Mercer Alloys Corporation	Greenville
Metals Engineering Company	Reading
Nuclear Materials & Equipment Co.	Apollo
Penn Nuclear	Penn

TENNESSEE

American Lava Corporation	Chattanooga
Union Carbide	Oak Ridge

WASHINGTON

Boeing Company	Seattle

WEST VIRGINIA	
Pennsylvania Glass Sand Corp.	Hancock
WISCONSIN	
Ladish Corporation	Milwaukee

Thomas Register, Dec. 1968 Ed., and other sources.